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Effect of Lime, N and P Salts on Nitrogen Mineralization, Nitrification Process and Priming Effect in Three Soil Types, Andosols, Luvisols and Ferralsols

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Abstract

Incubation studies were conducted to determine the effect of lime at the rate of 10tons ha^{-1}, Diammonium phosphate and Ammonium sulphate at 200kg$ha^{-1}$and Triple Superphosphate at 100kg ha^{-1} on nitrogen mineralization, nitrification process and priming effect. Three soil types were used namely luvisols from semi-arid Katumani, andosol and ferralsols from sub-humid Gituamba and Kitale, respectively. The soils were selected on types, pH, soil organic carbon content, land use and Climate. The soils were incubated aerobically in polythene bags for 120 days at room temperature and mineral N determined at specified periods during the experiment. Mineralized N was significantly higher ($p \leq 0.05$) under the various treatments compared to the control except for Kitale ferralsols. In the ferralsols, liming though it increased N mineralization was not significant compared to the control. Addition of salts increased production of mineral N suggesting a priming effect where DAP, AS and TSP were added. Addition of TSP and DAP increased N mineralization and was attributed to steady increase in microbial biomass as a result of P. The N mineralization rates were higher in the topsoil compared to the subsoil with the Andosols registering highest amounts released. Nitrate production was positively correlated with soil pH in Gituamba andosols only and this could be attributed to presence of acid adopted strains which are active at low pH levels.

Key words: N mineralization; nitrification; priming; soil types; pH and Organic carbon

INTRODUCTION

Nitrogen (N) is one of the most limiting nutrient to the growth of almost all crops in terrestrial ecosystems. The dynamics of inorganic N (NH_4^+, NO_3^-) has been intensively studied in soils, and increasingly research has been focused on the dynamics of soil organic N in agricultural soils. N in soil surface is predominantly organic (≈98%) (Bremner, 1951) and in this form, it is unavailable for plant and microbial use in the soil. It means therefore that it has to be converted to forms available for plant use such as NH_4^+, NO_3^-. The rhizosphere is the soil zone in which microbial activity is influenced by plant roots, distinguishing it from 'bulk' soil (Berendsen et al., 2012; Garbeva et al., 2004**;** Herman et al., 2006; Marschner et al., 2001). Active interaction occurs among plant roots, soil and microbes in rhizosphere soils (Herman et al., 2006; Lambers et al., 2009; Singh et al., 2004) resulting in an increase of soil N mineralization, which correspondingly increases net plant N assimilation (Bardgett and Chan, 1999; Bregliani et al., 2010).

The conversion of organic N to more mobile, inorganic state is known as "Nitrogen mineralization" and is accomplished in two steps: ammonification (production of NH_3 from organic matter) and nitrification (conversion of NH_4^+ to nitrates) (Myrold and Bottomley, 2007). The reverse i.e. incorporation of inorganic to organic forms, is known as immobilization. The opposing processes, immobilization-mineralization occurs simultaneously in most ecosystems, for example in soil, where organic material is undergoing microbial decomposition ((Duong, 2009; Moradi et al., 2014). Mineralization of N is the result of metabolism of a multitude of microbial strains, mostly chemo-heterotrophs (Weil and Brady, 2016). Because the ultimate liberation of NH_4^+ from organic matter (OM) is associated with many physiologically dissimilar microorganisms (MOs), N is mineralized occurs in most extreme conditions (Alexander, 1977). However,

the amount of NH_4^+ that accumulates varies with the nature of organisms, the substrate, soil type and environmental conditions (Amoo and Babalola, 2017; Karuku, 1989).

The breakdown of organic compounds containing N is through proteolytic enzymes synthesized extracellular by MOs' (Arnosti et al., 2013**)** in a process known as proteolysis, whereby proteins are hydrolysed into simpler units of peptides and amino acids. The release of NH_4^+ is then accomplished from amino acids through ammonification process. The rate of mineralization-immobilization is influenced by the C: N ratio, type of organic substrate, soil moisture content, temperature and aeration of soil (Zaman and Chang, 2004). Significance of some soil variables to N mineralization has been established under laboratory conditions. These includes texture with emphasis on varying aggregate sizes (Craswell and Waring, 1972; Van Veen, and Kuikman, 1990), soil moisture where mineralization has been found to vary directly within available range (Reichman et al., 1966; Karuku, 1989; Van Veen and Kuikman, 1990) and OM, particularly that which accumulates under pastures (Huntjens, 1972). Soil organic matter (SOM) can be: (i) physically stabilized, or protected from decomposition, through micro aggregation, or (ii) be intimately associated with silt and clay particles, and (iii) can be biochemically stabilized through the formation of recalcitrant SOM compounds (Six et al., 2002). Other factors being equal, production of inorganic N has been shown to be greater in neutral than in acid soils (Ishaque and Cornifield, 1972; Mochoge, 1981; Karuku and Mochoge, 2018), although some soils show little influence of pH on N transformations.

MATERIALS AND METHODS

Research Methodology

The need for satisfactory laboratory methods for obtaining an estimate of the amount of N likely to be made available for crop growth by mineralization of SOM during the growing season of a crop has been a matter of great concern. Numerous studies of biological and chemical approach have been conducted (Keeney and Bremner, 1966; Gianello and Bremner, 1986; Stanford and Smith, 1972; Stanford, 1982; Karuku, 1989; Karuku and Mochoge, 2018). It is generally accepted that the most reliable methods currently available are those involving determination of inorganic N produced by incubation of soil samples under aerobic and anaerobic conditions (Stanford, 1982; Gianello and Bremner, 1986; Karuku, 1989; Karuku and Mochoge, 2016; 2018). Incubation of soil samples in-situ involves burying of soil samples in polythene or mesh bags under soils at different depths from sites of sampling and monitoring frequently the inorganic N release (Hanselman et al., 2004). The method exhibits some field conditions but use of disturbed soil samples and sand-witching of bags in between soil layers puts it slightly off from actual field situations in terms of moisture and air regimes (Karuku, 1989; Mochoge, 1981). Moreover bags used have been often attacked by insects and therefore the results have not been very reliable (Karuku, 1989; Mochoge, 1981). Different incubation methods have been used and these include incubating soils in-situ (in bags), use of column studies and incubating of soil samples in polythene bags in the laboratories.

Three soil types were selected on the basis of groups, agro-ecological zone, organic matter content and land use. These were the Gituamba andosols, Kitale ferralsols and Katumani luvisols (WRB, 2015). Gituamba is centered on coordinate $0^0$45'S-$36^0$51'E where the Geology is mainly Basalts and Basaltic Conglomerates of Simberian Series. The land is under tea and pyrethrum cultivation under ecological zone II; r/E 82%. The soils are

acidic, well drained dark to dark-reddish clay. The Kitale ferralsols were sampled on center coordinates $1^0$01'N-$34^0$39'E and the Geology consists of Basement system of Gneisses, Schists rich in Feldspars, Biotite, Hornblende and Garnet with minor exposure of granite and Pegmatite dykes. The land is mainly used for maize cultivation and pasture research. It is in agro-Eco-zone III, r/E 66%. The soils on one side are well drained deep to moderately deep, reddish brown to yellowish red, friable clay on upper valley slopes. The other is poorly drained dark grayish brown in valley bottoms. Main clay mineralogy is kaolin. There are significant quantities of illite and montmorillonite. The Katumani luvisols are on coordinates $01^0$35 'S-$37^0$14'E. The Geology of the area is mainly Quartzo-feldspartic gneiss of the Precambrian basement system. The land was originally under Acacia bush which has been cleared to pave way for Cereals such as maize, sorghum and also beans and pastures. It is in Eco-zone IV. The soils are well drained sandy clay.

Soil Sampling

The soil samples were taken from the 0-15 and 15-30 cm depth. A profile pit 40cm deep was dug and the 15-30cm depth sampled first to avoid contamination from above layer. The samples were placed in special sampling bags, sealed and placed in cool boxes before transportation to the laboratory for processing. Undisturbed samples were also taken using core rings for physical determinations of bulk density and hydraulic conductivity.

Preparation of Soil Samples for Incubation

The soil samples were weighed in 2kg for each treatment. For Gituamba andosols and Kitale ferralsols, there were five treatments each: Control which was the normal untreated soil, Lime added at 10t ha^{-1}. Ammonium sulphate (AS) and Diammonium phosphate (DAP) each at 200kg $ha^{-1}$and Triple superphosphate (TSP) at 100kg ha^{-1}. For

Katumani luvisols, all treatments except lime were applied as this soil has a high pH (Table 1) hence requires no lime. The soils were spread in a thin layer for treatments to be applied evenly. 1g of AS and DAP, 0.5g of TSP and 10g of lime ($CaCO_3$) were weighed, dissolved in distilled water and then evenly sprayed on the thin layer of soil to achieve some uniformity. Distilled water was added to the soil up to field capacity. The soils were then put in polythene bags, sealed to prevent excess moisture loss and incubated at room temperature in the laboratory for 120 days.

Mineralization and nitrification processes were followed by changes of ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) in the soils at 0, 60 and 120 days since commencement of incubation. Moisture content and soil pH were also determined during this period of extraction where 10g of soil were used for each sampling period. Extraction was done using 2N KCl and the mixture was filtered, and the filtrate analyzed for mineral N using micro Kjeldahl method (Bremner, 1996).

Calculation: 1 ml of 0.001N H_2SO_4 = 14µgN; hence %N = $\left(\frac{(Titre - Blank).14}{10,0000}\right)$ I

$$kgN/ha = \frac{Soil\ depth\ x\ Bulk\ density\ Conc.\mu gN\ x\ area\ (cm^2)}{Weight\ of\ Soil\ x\ 10^9} \quad II$$

RESULTS AND DISCUSSION

Soil characterization

The behavior of nitrogen in soils is controlled by the physical, chemical and biological properties of the soil. This being the case, it was therefore necessary to know some of the salient properties of the three soils used (Table 1). The pH ranged from 4.0 in Gituamba andosols (0-15 cm) to 7.0 in Katumani luvisols (15-30 cm) depths. The pH is markedly influenced by the parent material and climatic conditions of the site. Gituamba area is

relatively humid and soils derived from volcanic activity hence low pH. Low pH also has a marked influence on Exchangeable Aluminium (Al) as clearly seen in Gituamba andosols with highest Al content of 4.6me and 3.3me/100g soil in the 0-15cm and 15-30cm depth, respectively. Analyzed Al was found to be highly negatively correlated to soil pH ($r = -0.88$, $P \leq 0.05$). The pH was also found to be significantly and positively correlated with percent base saturation ($r = -0.86$, $P \leq 0.05$).

The soils also gave different though expected pattern of organic carbon (OC) and total nitrogen (TN) distribution in the profiles. Both the %OC and TN decreased with depth within soil profile, a phenomenon undoubtedly due to the addition of OM mainly at the top. Nitrogen is an integral part of organic carbon. Gituamba Andosols had the highest of both 7.9 and 0.6 % of OC and TN, respectively. The C: N ratio differed in the two depths in all soil groups with the ratio lower in the 15-30cm depth. Low C: N ratio ranged from 5.3 in Katumani luvisols, to 22.5 in Kitale ferralsols 0-15cm depths. C: N rations are controlled by conditions such as moisture, temperatures and presence of substrate to be mineralized. The C: N ratios observed were within the range that favors net N-mineralization (Kaleeem et al., 2015; Karuku and Mochoge, 2016).

Exchangeable potassium (Exch. K) was very low in Kitale ferralsols followed by Katumani luvisols. For Gituamba andosols, exch. K was high at 3me/100g soil. These Andosols are derived from volcanic ash hence high K content. Keter (1974) suggested that East African rocks are often rich in this element especially when derived from volcanic rocks. Generally, Calcium (Ca), Magnesium (Mg), Sodium (Na) and K were higher in top than sub-soil with exception in Katumani luvisols where Ca and Mg were lower, a fact

partly attributed to leaching from above or simply reflected supply of cations from parent rock (Karuku and Mochoge, 2016).

Table 1. Some salient characteristics of the three soil groups of the study

Soil sampling site and groups	Gituamba andosols		Kitale ferrallisols		Katumani luvisols	
Soil Properties/ Depth (cm)	0-15	15-30	0-15	15- 30	0-15	15-30
pH-water	4.0	4.1	5.6	5.6	6.6	7.0
pH-KCl	3.9	4.0	4.4	4.5	4.8	5.6
CEC (me/100g soil)	28.6	26.7	15.3	13.4	13.4	12.1
ECEC(me/100g soil)	11.6	10.2	11.4	9.1	9.5	10.7
Ca(me/100g soil)	0.7	0.3	4.7	2.9	5.7	6.3
Mg(me/100g soil)	0.5	0.1	2.4	2.0	1.3	1.9
Na(me/100g soil)	0.5	0.4	1.0	0.5	0.6	0.4
K(me/100g soil)	4.3*	3.3*	1.5	1.2	1.5	0.9
% Base Saturation	21.0	19.5	62.7	55.2	61.4	78.5
Exch Al^{3+} (me/100g soil)	4.6	3.3	1.0	0.8	1.1	0.9
Exch H^{+}(me/100g soil)	1.0	0.7	0.9	0.9	0.4	0.3
Available P (ppm)	12.5	10.0	2.5	1.5	46.0	29.0
% Total N	0.6	0.5	0.2	0.1	0.2	0.1
% Organic C	7.9	4.8	4.5	1.8	1.0	0.5
C:N	12.8	9.2	22.5	13.9	5.7	5.3
Bulk Density (gcm^{-3})	0.6	0.8	1.2	1.1	1.4	1.3
% Sand	40.3	38.3	41.9	37.3	68.6	74.2
%Clay	19.9	27.9	52.9	55.0	23.9	22.4
%Silt	39.8	33.8	5.2	7.7	7.5	3.4
Textural Class	Loam	Loam	Clay	Clay	Sandy Clay Loam	Sandy Clay Loam

Cation exchange capacity (CEC) is a measure of soil fertility and was observed to be higher in the top than in the sub soils in the soil groups. The clay content was highest in Kitale ferrallisols at 52.9 and 55.0% and lowest in Katumani luvisols at 23.9 and 22.4% in the 0-15 and 15-30cm depths, respectively for each soil group. Katumani soils had highest sand content at 68.6 and 74.3% for the 0-15 and 15-30cm depths, respectively. The texture of the three soil groups varied greatly and could have been influenced by such factors as the vegetation of the location, climate of the area as well as the parent material from which the soils were derived. Gituamba soils are loamy; Kitale clayey and Katumani are sandy clay loam. The bulk density (ϱb) was highest in Katumani luvisols at 1.4 and 1.3gcm^{-3} and lowest in Gituamba Andosols at 0.6 and 0.8gcm^{-3} for the 0-15 and 15-30cm depths, respectively and seems to reflect on the texture of respective soils. Soils low in clay content and are high in sand content like Katumani luvisols tend to exhibit higher ϱb and vice versa (Chaudhari et al., 2013; Sakin, 2012; Perie and Ouimet, 2007; Sakin et al., 2011). However,

Effect of Lime, N and P salts on nitrogen mineralization in Gituamba andosols during incubation

Figure 1 show the effect of lime, N and P salts on N mineralization in Gituamba andosols and where limed with $CaCO_3$, the N mineralization increased from 75.9µgN to 169.0µg N/g soil from 0 to 60 days and reaching a peak of 170.2µgN at 120th day of incubation in the 0-15cm depth. In the 15-30 cm depth, the increase was from 69.3 to 150µgN and then declined to 147.7µgN/g soil at 120th day of incubation. The same trend was observed in the control but with less amounts mineralized than limed soils and ranged from 79.9 to 130.2µg N/g soil from 0 to 60 days and then declined to 106µg N/g soil in the 0-15cm depth after 120 days of incubation. Again the 15-30 cm depth realized lower amounts of 69.3, 137.9 and 98.2µgN/g soil mineralized in the 0, 60 and 120 days of incubation, respectively.

Addition of DAP in the andosols increased N mineralized from 166.8 to 205.1µgN/g soil from 0 to 60 days and then declined to 199.9µgN/g soil after 120 days of incubation in the 0-15cm depth. For the 15-30 cm depth, the increase was from 160.2 to 193.5µgN, then declined to 191.2µgN/g soil after 120 days. In the case of AS, N mineralization increased from 166.8 to 209µgN from 0 to 60 days then decreased to 184.6µgN/g soil after 120 days in the 0-15 cm depth. For 15-30cm depth, N-mineralization was 160, 185.1 and 178.2µgN/g soil in the 0, 60 and 120 days, respectively in the andosols. Mineralization rates followed same trend and was more in the 0-15cm depth (Table 2). The highest N mineralization rates were observed in limed soils at 5.53 and 4.45µgN/g soil/week in 0-15 and 15-30cm depths, respectively.

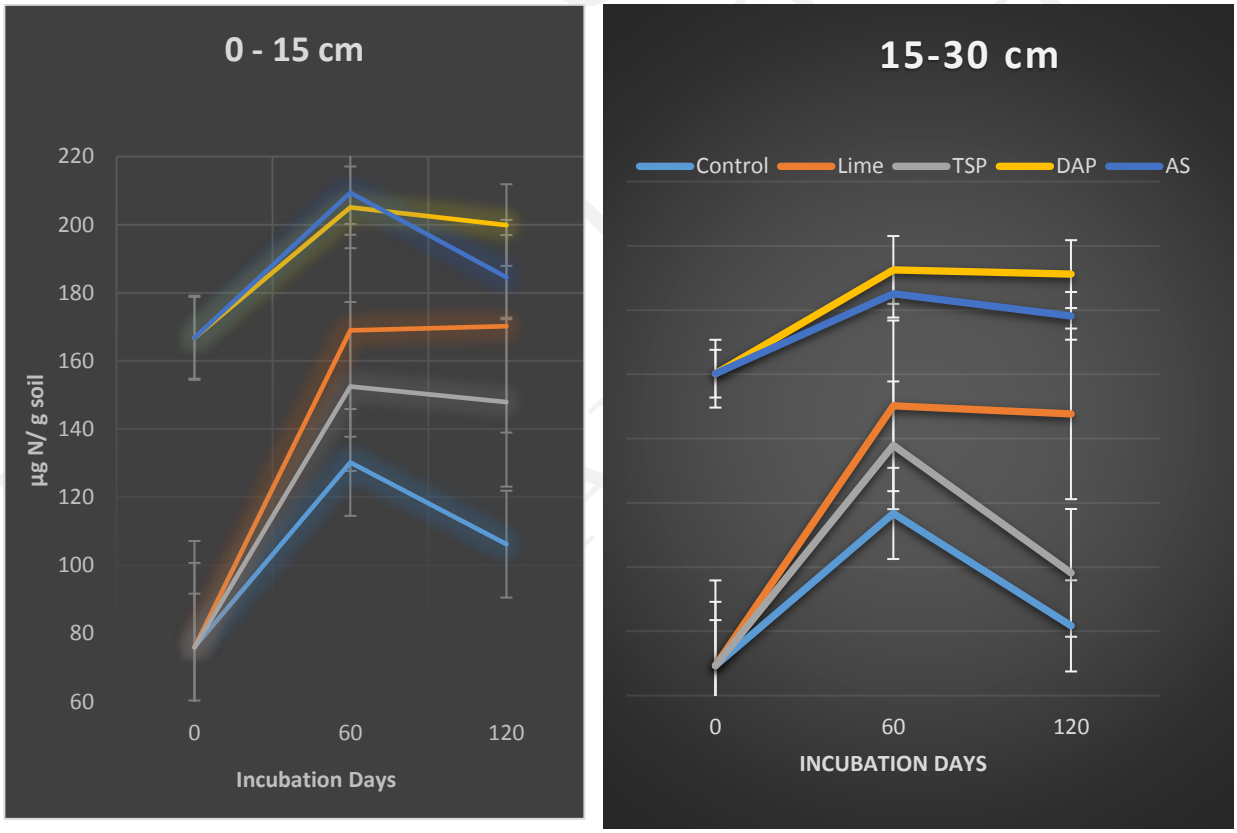

Fig.1. *Effect of Lime, N and P salts on nitrogen mineralization in Gituamba andosols during incubation*

The lowest N mineralization rate values were observed in soils treated with ammonium sulphate at 1.05µgN/g soil/week in both depths. Addition of TSP also had high N-mineralization rate of 4.20µgN/g soil/week in the 0-15cm depth for the andosols. DAP had mineralization rates of 1.96 µgN/g soil/week and 1.82µgN/g soil/week while control had 1.75 and 0.7µgN/g soil/week in the 0-15 and 15-30cm depths, respectively. Liming Gituamba andosols increased N mineralization rate significantly ($p \leq 0.05$) compared to all other treatments. The soil pH in this soil also increased markedly after liming from 4.0 to 5.7 and from 4.1 to 5.8 in the 0-15 and 15-30cm depths, respectively (Table 5). Where TSP was added and for control, there was only very slight variation in pH from 4.0 to 4.2 in both depths. Where N salts were applied, the pH declined from 4.0 to 3.9 in 60 days and then increased to pH 4.0 at end of incubation period. Increase in pH where lime was added created a favourable environment for microbial activities to flourish enabling them to act on accumulated organic N in the soil and thus releasing mineral N (Sarathchandra and Upsdell, 1981; Smillie and Curtin, 1983).

Table 2. Net-N mineralization (µgN/g soil) and mineralization rates (µgN/g/wk.) under different treatments in three soil groups during incubation

		Gituamba andosols		Kitale ferralsols		Katumani luvisols	
Treatment	Depth (cm)	N-Min µgN/g soil	N-min' rate µgN/g/wk.	N-Min µgN/g soil	N-min' rate µgN/g/wk.	N-Min µgN/g soil	N-min' rate µgN/g/wk.
Control	0-15	30.3	1.75	10.4	0.63	28.4	1.68
	15-30	12.4	0.70	11.3	0.63	23.8	1.40
Lime	0-15	94.3	5.53	12.6	0.77	-	-
	15-30	78.4	4.45	11.7	0.70	-	-
TSP	0-15	72.0	4.20	18.3	1.05	42.8	1.52
	15-30	28.9	1.68	18.8	1.12	26.2	1.54
DAP	0-15	33.1	1.96	-43.8	-	102.6	6.02
	15-30	31.0	1.82	-46.0	-	77.6	4.55
AS	0-15	17.8	1.05	-60.3	-	84.1	4.90
	15-30	18.0	1.00	-54.6	-	52.9	3.08

High pH could also have increased nutrient availability for microorganisms (MOs) thus contributing to the high N mineralization rates. Addition of N salts led to high production of mineral N though net mineralization was low. The apparent high production of mineral N was as a result of the added N from the inorganic fertilizer which was then acted on by the MOs hence releasing mineral N (NH_4^+ and NH_3^-). Also addition of inorganic fertilizers led to a drop in pH though this drop did not hinder production of mineral N. The low net N mineralization in soils treated with N inorganic fertilizers is due to this added N as MOs has enough already for their biological needs hence no need to act on the organic N in soils. The decline in mineralization rate at end of incubation for all treatments and in soil depths could probably be due to reduction of available mineralizable substrates towards the end of the incubation period. This could also result from immobilization of N by MOs as their population proliferated during the long incubation period (Budimir, 1980). Immobilization phenomena might also represent a shift in microbial population or species diversity that could result from an extended incubation period at constant temperature.

Among the two N salts, DAP promoted more mineral N production than AS (Table 2). However this net N mineralization was not significant and this could be attributed to presence of P in the DAP. Presence of P could have boosted microbial growth (Munevar and Wallum, 1977; Stotzky and Norman, 1961) especially in acid soils where native P is likely to be fixed. This also applies to liming of soils which reduces the chances of P fixation as pH increases. Microbial population is generally limited by P deficiency which then depress N mineralization. The decline in mineralized N with depth could be attributed to low OM content down the profile or a decline in microbial population. It shows therefore that addition of N salts did not have any stimulating effect on organic N mineralization in soils while addition of inorganic P salt did stimulate N mineralization leading to relatively high mineral N production in the andosols (Table 4). Among

biological properties, activities of beneficial MOs are adversely affected by soil acidity, which has profound effects on the decomposition of OM, nutrient mineralization, and immobilization, uptake, and utilization by plants, and consequently on crop yields (Fageria and Baligar, 2008).

Effect of Lime, N and P salts on nitrogen mineralization in Kitale ferralsols during incubation

Figure 2 shows the effect of lime, N and P alts on N mineralization in Kitale ferralsols. Addition of lime showed an increase in N release above the control. The increase was from 32.9µgN to 55.4µgN/g soil from 0 to 60 days then decreased to 45.5µgN/g soil after 120 days of incubation for 0-15cm depth. The same trend was observed in the 15-30 cm depth. In the controlled experiment, N release was 32.9, 50.7 and 43.3µgN/g soil in the 0, 60 and 120days, respectively for 0-15cm depth. The 15-30cm depth showed same trend but with less amounts. Addition of TSP in the ferrallisols showed same trend as lime treatment in both depths but amounts of N released were higher than in limed soils. The amount observed were 32.9, 57.1 and 51.2µgN/g soil for 0-15 cm depth and 25.8, 52.6 and 44.62µgN/g soil for 15-30 cm depth in the 0, 60 and 120days, respectively.

Addition of N inorganic salts depressed production of mineral N. With DAP addition, N release declined from 123.9 to 74.3 and then increased to a partly 80.12µgN/g soil for 0-15 cm depth while in the 15-30 cm depth, N release declined continuously from 116.7 to 72.8 and finally to 70.72µgN/g soil in 0, 60 and 120days of incubation. With AS addition, the decline was 123.9 to 73.2µgN/g soil in the 0-15 cm while in the 15-30 cm depth it was from 116.7 to 62.12µgN/g soil in 0 to 60 days and then increased slightly to 62.12µgN/g soil after 120 days of incubation. Concentrations of mineral N (µgN/g soil) and mineralization rates (µgN/ha/week) for Kitale ferralsols are shown in Table 2 between the initial and 120 days of incubation. The mineral N produced within the incubation

period was highest in TSP treated soils in both 0-15 and 15-30cm depths at 18.3 and 18.8µgN/g soil, respectively. Control and limed soils have generally similar amounts at around 11µgN/g soil on average while inorganic N salts added returned negative N between initial and at end of incubation thus leading to a depression in N mineralization. TSP addition showed increased N mineralization rates of 1.05 and 1.12µgN/ha/week than any other treatment in the 0-15 and 15-30cm depth, respectively.

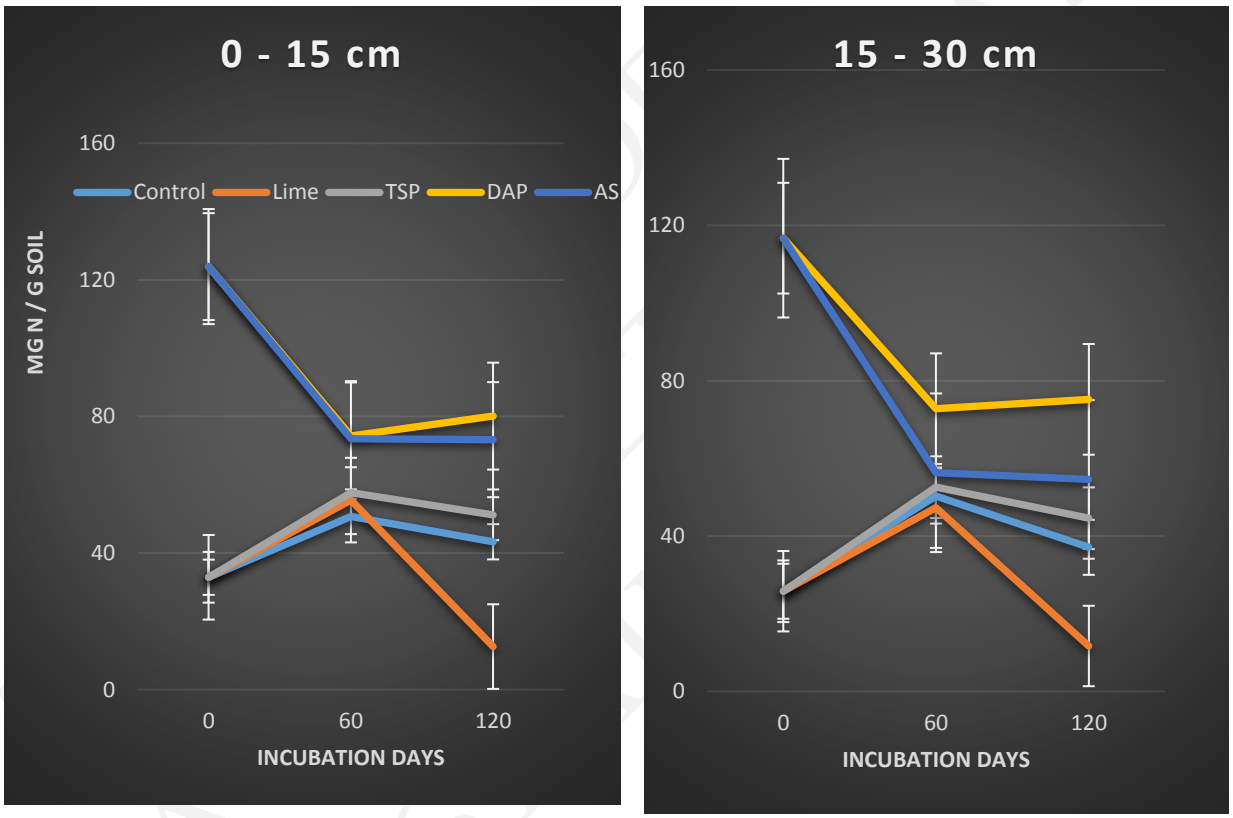

Fig 2: Effect of Lime, N and P salts on nitrogen mineralization in Kitale ferrallisols during incubation

Lime came second at 0.77 and 0.70µgN/ha/week, in 0-15 and 15-30 depths, respectively and followed closely by the control at 0.63µgN/ha/week in both depths. N-salts caused a depression and was highest where AS was added. Lime addition increased N mineralization in ferrallisols above control and also raised soil pH from 5.6 to around

7.75μgN/ha/week in both depths. TSP did not significantly affect the soil pH (Table 5) while addition of N salts lowered it from 5.6 to 4.85μgN/ha/week for both depth salts and depths. The non-significant effect of N mineralization after liming Kitale ferralsols simply qualify the fact that it is not necessary to lime these soils (Anon, 1976) as the NH_4^+ ions are very elusive and difficulty to trace due to inherent Micaceous clay minerals. The mineralizable organic N content in this soil was also low and therefore addition of lime could not make an impression here. The low organic N content could have played a major part in the low mineralization N values obtained as the substrate comprising the N to be mineralized normally influences the amount of N to be released (Stanford and Smith, 1972). There could also be low microbial activity paying a role.

Addition of N salts to the ferralsols depressed amount of mineral N released from original mineralizable organic N and could be attributed to their acidifying effect (Table 5) in the soils thus greatly affecting the MOs responsible for the mineralization process. The increase in pH towards the end of incubation could account for the slight increase in N mineralization for DAP (0-15 cm) and AS (15-30 cm depths) treatments. Increase of N mineralization above the control was only experienced in the first 60 days of the experiment before declining towards end of incubation (Figure 2). Though the increase was insignificant, added inorganic P promoted mineral N release from soil organic nitrogen. The available P and exchangeable K in this soil was rather low and could have affected mineralisation process as the two elements affect both the microbial biomass and activity (Bartholomew and Clark, 1965). The high N mineralization in the 0-15 cm compared to the 15-30cm depth could be attributed to, first; the lower OC in the 15-30 than in the 0-15cm depths. Secondly, the 0-15cm depth has a higher N mineralization potential (Karuku and Mochoge, 2018) hence higher rate and bigger magnitude of mineralizable N than the 15-30cm depth.

Effect of N and P salts on nitrogen mineralization in Katumani luvisols during incubation

Addition of N salts to Katumani luvisols significantly ($p \leq 0.05$) increased production of mineral N (Figure 3) throughout the incubation period. N mineralization increased from 97.6 to 200.4µgN/g and from 97.0 to 174.6µgN/g soil from 0 to 120 days in the 0-15cm and 15-30cm depths, respectively where DAP was added. With addition of AS fertilizer, the increment of mineral N was from 97.6 to 181.7µgN/g and from 97.0 to 149.9µgN/g soil from 0 to 120 days in the 0-15cm and 15-30cm depths, respectively. Same trend though low, was observed in the control where the increment ranged from 6.9 to 35.3µgN/g and from 6.1 to 29.9µgN/g soil in the 0 to 120 days in the 0-15cm and 15-30cm depths, respectively. TSP addition increased mineral N production from 6.9 to 49.7µgN/g and from 6.1 to 32.3µgN/g soil in the 0-15cm and 15-30cm depths, respectively from 0 to 120 days of incubation period. In all treatments, the 0-15cm produced higher mineral N than the15-30cm depth in Katumani luvisols. The increase in mineral N was very steep from 0 to 60 days then became gentle towards end of experiment in all treatments. Among N salt treated soils, addition of DAP produced more mineral N (102 and 77.6µgN/g soil) than AS (84.1 and 52.9µgN/g soil) in the 0-15cm and 15-30cm depths, respectively. Both depths showed same trend though the upper depth produced more mineral N than the lower. The N mineralization rates were above 3.08µgN/ha/week where N salts were added compared to all other treatments. Soil pH dropped from 6.6 to 5.5 in the 0-15cm depth with addition of DAP (Table 5). With soil treated with AS, pH dropped from 6.6 to 5.4 and from 7.0 to 5.0 in the 0-15 and 15-30cm depths, respectively after 120 days.

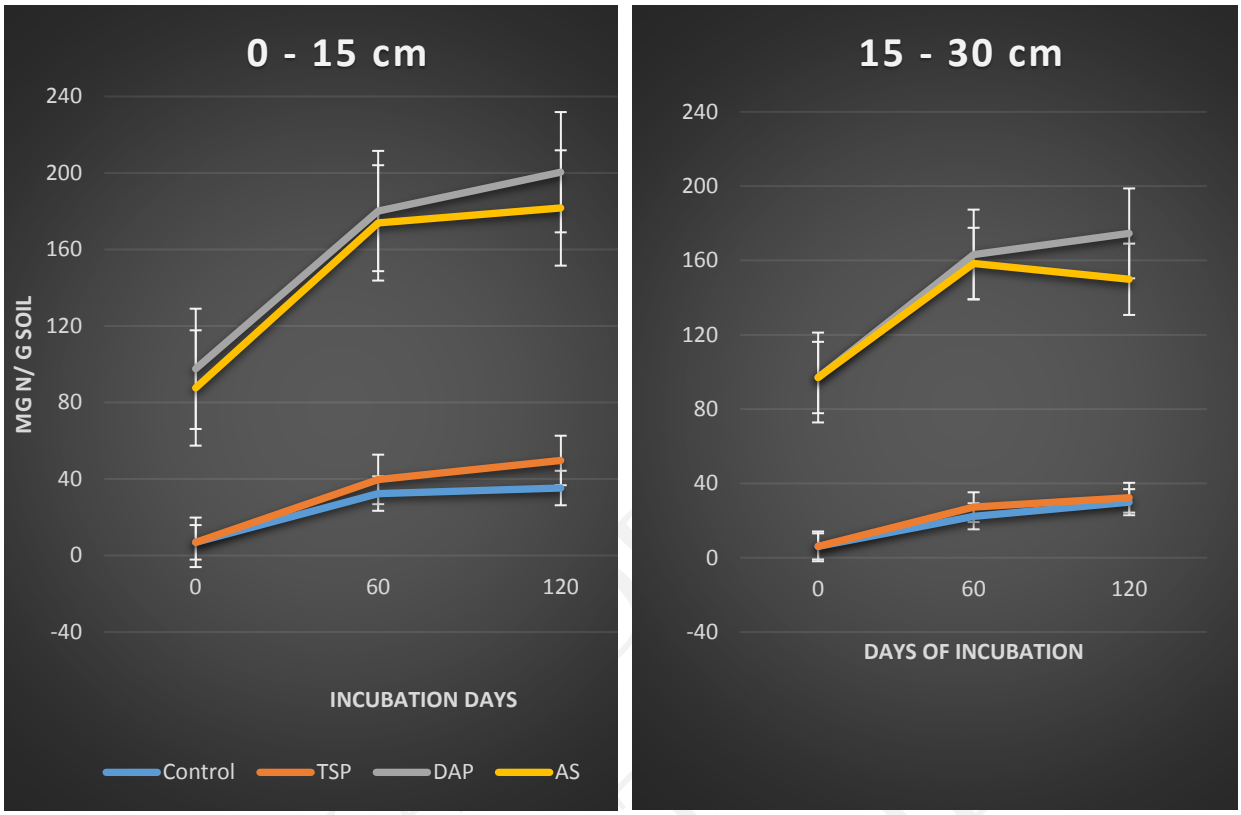

Fig 3: *Effect of N and P salts on nitrogen mineralization in Katumani luvisols during incubation*

Addition of inorganic P salts also increased N mineralization and mineralization rates (2.52 and 1.54µgN/ha/week) above the control (1.68 and 1.40 µgN/ha/week) for the 0-15cm and 15-30cm depths, respectively from 0 to 120 days of incubation period and was only significant ($p \leq 0.05$) at 60th day of incubation (Table 2). The soil pH also dropped with addition of inorganic P salts from 6.6 to 6.4 and from 7.0 to 6.1 in the 0-15cm and 15-30cm depths, respectively from 0 to 120 days of incubation period (Table 5). The decline however was not as steep as soil with added N salts. Liming was not done in this soil due to its high inherent pH unlike in Gituamba andosols and Kitale ferralsols. In all treatments, N mineralization was higher compared to the control (Table 2) with DAP leading in amounts, followed by AS and then TSP. Katumani soils has been observed to have low nitrogen mineralization potential (No) (Karuku and Mochoge, 2018), hence addition of N salts increased the N content in the substrate to be mineralized (Stanford

and Smith, 1972; Karuku, 1989; Karuku and Mochoge, 2018). This in turn led to the high amount of N mineralized (Table 2) compared to the control and TSP treated soils. Among the two N sources, DAP mineralized significantly ($p \leq 0.05$) higher N amounts in the 60 and 120 days of the experiment compered to AS and this was attributed to the N and P interaction (Munevar and Wallum, 1977). Presence of P could have influenced microbial population and biomass as well as activity leading to higher release of mineral N in soils treated with DAP, a trend observed in both depths.

Mean separation indicated that the limed, control and soil treated with TSP had higher N mineralized compared to soils treated with inorganic N salts (Table 3). Limed soils had significantly ($p \leq 0.05$) the highest N mineralized compared to all other treatments.

Table 3. N mineralization mean separation values (µgN) between treatments at 60 and 120 days of incubation

	Gituamba andosols		Kitale ferralsols		Katumani luvisols	
Mean Separation	60 days	120 days	60 days	120 days	60 days	120 days
T2-T5	53.25*	68.45*	77.45*	69.6*	ND	ND
T2-T4	51.70*	54.30*	68.80*	57.05*	ND	ND
T2-T1	36.15*	65.00*	0.9NS	1.3ns	ND	ND
T2-T3	14.40*	35.90*	-3.75NS	6.4*	ND	ND
T3-T5	38.85*	32.55*	81.2*	76.00*	-41.85*	34.00*
T3-T4	37.30*	18.40NS	72.55*	63.45*	47.35	55.60*
T3-T1	21.75*	29.10*	4.65NS	7.70*	3.1NS	8.4NS
T1- T5	17.10*	3.45NS	76.55*	68.30	-44.95*	-42.40*
T1- T4	15.55*	-10.7*	67.90*	55.75*	-50.45*	64.00*
T4- T5	1.55NS	14.15*	8.65NS	12.55*	5.5NS	21.60*
D1-D2	10.60NS	15.76NS	8.64NS	0.80NS	11.55NS	19.35NS

Legend: T1: Control. T2: Lime. T3: TSP. T4: DAP. T5: AS. D1: 0-15cm. D2: 15-30cm. NS: Not significant. ND: Not determined. Star (*) Significant after mean separation

TSP addition significantly ($p \leq 0.05$) increased N mineralization above control and N salt treated soils after 60 days of incubation. Among the two N added salts, DAP had higher N mineralization though not significant (NS) (Table 3) compared to AS. In all treatments, production of mineral N decreased with depth though NS different.

Priming ***effects of Lime, N and P salts on nitrogen mineralization in three soils, andosols, ferralsols and luvisols during incubation***

Increment in N mineralization is shown in Table 4 where a positive (+ve) sign indicates priming or stimulation of N mineralization and a negative sign (–ve) retardation or depression. The highest stimulation was observed in limed Gituamba andosols at 140.9 and 145.3kgN/ha while Kitale ferralsols had only 4.8 and 0.9kgN/ha stimulation in 0-15 and 15-30cm depth, respectively. The increased N mineralization (+ve) suggests a priming effect which is the stimulation effect of stable humus in soils (Broadbent, 1949,; Broadbent and Bartholomew, 1948; Walker et al., 1956). In this case, it was obtained by first subtracting N mineralized between 0 and 120 days in all treatments. The values obtained were then subtracted from values obtained in the control within that period. This gave either +ve or –ve values indicating stimulation/priming effect or retardation/depression, respectively.

Addition of TSP showed a priming effect in all three soils with Gituamba andosols having the highest of 91.8kgN and 36.4kgN/ha in the 0-15cm and 15-30cm depths, respectively.

Kitale ferralsols had 17.5kgN and 16.6kgN/ha while Katumani luvisols had 31.7 and 5.4kgN/ha in the 0-15cm and 15-30cm depths, respectively where TSP was added. With addition of DAP, stimulation effect was only observed in Gituamba andosols at 6.2 & 1.7kgN/ha and Katumani luvisols at 163.3 & 118.4kgN/ha in the 0-15cm and 15-30cm depths, respectively. For Kitale ferralsols, addition of DAP depressed N mineralization at -119.1 and -126.0kgN/ha in the 0-15cm and 15-30cm depths, respectively. Ammonium Sulphate stimulated Katumani luvisols at 122.1 and 64.24kgN/ha in both depths, respectively and only 12.4kgN/ha only for Gituamba andosols in the 15-30cm depth. The ferralsols treated with AS showed a negative effect. This N was probably immobilized or lost through denitrification processes.

The priming effect in the Andosols could have been due to increased pH (Table 5) after liming thus favouring microbial population, diversity and activities in the soil. For the ferralsols, the pH increased to above 7.0 (Table 5) following liming and this could have led to N losses through volatilization and denitrification hence low or negative stimulation effect. Terman (1979) observed losses of ammonia gas as pH increased while nitrification following liming favours N_2O losses especially in alkaline pH (Focht and Verstraete, 1977). In all three soil types, addition of inorganic P salts showed an increase in net N mineralization.

Table 4. Priming effect on N mineralization (kgN/ha) by treatment of Lime, N and P salts in three soil groups during incubation

Site/Type	Treatment	Depth (cm)	Initial 0 days	Final 120 days	Difference 0-120	Stimulation
Gituamba andosols	Control	0-15	167.1	233.6	66.5	NA
		15-30	152.5	177.7	27.2	NA
	Lime	0-15	167.1	374.5	207.4	+140.9
		15-30	152.5	325.0	172.5	+145.3
	TSP	0-15	167.1	325.4	158.3	+91.8
		15-30	152.5	216.1	63.6	+36.4
	DAP	0-15	367.1	439.8	62.7	+6.2
		15-30	352.5	420.7	68.2	+1.70
	AS	0-15	367.1	406.1	39.1	-27.4*
		15-30	352.5	392.1	39.6	+12.4
Kitale ferralsols	Control	0-15	72.5	95.2	22.7	NA
		15-30	56.8	81.6	24.8	NA
	Lime	0-15	72.5	100.0	27.5	+4.8
		15-30	56.8	82.5	25.7	+0.9
	TSP	0-15	72.5	112.7	40.2	+17.5
		15-30	56.8	98.2	41.4	+16.6
	DAP	0-15	272.5	176.1	-96.4	-119.1
		15-30	256.8	155.6	-101.2	-126.0
	AS	0-15	272.5	160.9	-111.5	-134.2
		15-30	256.8	136.6	-120.2	-145.0
Katumani luvisols	Control	0-15	15.1	377.7	62.6	NA
		15-30	13.5	65.7	52.2	NA
	TSP	0-15	15.1	109.4	94.3	+31.7
		15-30	13.5	71.1	57.6	+5.4
	DAP	0-15	215.1	440.9	225.9	+163.3
		15-30	213.5	384.1	170.6	+118.4
	AS	0-15	215.1	399.9	184.7	+122.1
		15-30	213.5`	329.9	116.4	+64.2

Legend. NA: Not applicable DAP: Diammonium Phosphate TSP: Triple superphosphate AS: Ammonium Sulphate Lime: Calcium carbonate

This is so even in the ferrallisols where TSP had the highest stimulation of 17.5 and 16.6kgN/ha for 0-15 and 15-30cm depths, respectively. This was higher than in any other treatment in this soil. Addition of inorganic P provides an essential nutrient to MOs especially in very acid soil thus boosting their population and activity (Stotzky and Norman, 1961) as well as species diversity.

Generally, DAP had a higher priming effect than AS with the exception of the andosols 15-30cm depth. This could be attributed to the presence of P interacting with available N to boost microbial population (Munevar and Wallum, 1977) and diversity plus their activities in soil. The same trend was observed in the other two soil types in both depths. For the ferralsols, the depression caused on N mineralization was higher with AS than DAP while in the luvisols, DAP had a higher stimulating effect than the TSP and this could be attributed to the presence of both N and P. Addition of extra P alone in the Katumani luvisols did not have any significant effect in this soil probably due to its high inherent P content (Table 1). It can therefore be concluded that addition of N and P salts has a priming effect on N mineralization. It appears to reflect on the physical-chemical properties of the soils. Liming soils have a positive priming effect more especially with acid soils.

Nitrification in three soil types and its effect on soil pH during incubation

Table 5 show nitrate (NO3) levels and pH changes during incubation of the three soil groups. The soil pH increased with lime treatment as incubation period progressed and in the same manner, nitrate levels showed the same trend. With addition of inorganic N salts, nitrification progressed although there was a drop in soil pH, which later increased

towards the end of the experiment. In limed Gituamba andosols, soil pH and nitrates produced were highest than any other treatment. This suggests a priming effect through liming of acid soils and further suggests that acidification does suppress nitrification process but does not curtail it completely (Ishaque and Cornified, 1972, Karuku, 1989). Addition of TSP in the andosols also showed a priming effect (Table 5) though the pH fluctuated slightly. Nitrification took place on applied ammonium-N (NH_4-N) and also from the soil N pool where N salts were added. This same observation was seen in Kitale ferralsols and Katumani luvisols, where both the NH_4-N applied and that from the soils were nitrified. Nitrate (NO_3-N) levels were correlated positively to pH ($r=0.46$; $p\geq0.05$) for the andosols and negatively for the ferralsols ($r= -0.46$; $p\geq0.05$) and luvisols ($r= -0.66$; $p\geq0.05$). The correlation between nitrates and pH was however not significant.

Kitale ferralsols had least production of nitrates of NO_3-N (Table 5) as it tended to retain N more in form of NH_4-N. Though pH decreased after 60 days of incubation where ferralsols were treated with N and P salts, some nitrification process continued to occur. In limed ferralsols, pH shot up to 7.6 and this could have led to volatilization of N in form of NH_3 gas thus leading to the low NO_3-N observed. Also Kitale soils being under grass cover contained many roots that could have inhibitory effects to the nitrifiers (Ellis, 1954). This soil tends to retain more NH_4-N than NO_3-N as it is developed under grass (Robinson, 1963). Perennial grass secretes small quantities of toxic substances which specifically inhibits activities of nitrifiers (Theron, 1951).

Table 5. Nitrate (NO3) levels and pH changes during incubation of the three soil groups.

Days			0			60			120		
Soil	Treatment	Depth	NO_3-N	NH_4-N	pH	NO_3-N	NH_4-N	pH	NO_3-N	NH_4-N	pH
Gituamba andosols	Control	0-15	37.8	129.2	4.0	155.9	130.6	4.0	196.7	36.8	4.0
		15-30	31.4	121.1	4.1	134.8	121.8	4.1	137.5	42.3	4.1
	Lime	0-15	37.8	129.2	4.0	232.6	139.3	5.5	243.5	131.0	5.7
(r=0.46;		15-30	31.4	121.1	4.1	192.2	137.9	5.8	193.1	131.9	5.8
p≥0.05)	TSP	0-15	37.8	129.2	4.0	205.6	129.9	4.0	222.8	102.6	4.2
		15-30	31.4	121.1	4.1	196.9	106.5	4.2	176.7	39.3	4.2
	DAP	0-15	37.8	229.2	4.0	137.0	137.0	3.9	137.6	302.2	4.0
		15-30	31.4	221.1	4.1	145.6	145.6	3.9	139.8	280.9	4.1
	AS	0-15	37.8	229.2	4.0	152.6	152.6	3.8	108.4	297.8	4.0
		15-30	31.4	221.1	4.1	134.3	134.3	3.9	117.8	274.4	4.0
Kitale ferralsols	Control	0-15	26.4	46.1	5.6	24.2	87.3	6.3	20.6	30.6	6.1
		15-30	17.3	39.5	5.6	18.8	91.9	6.2	10.0	10.0	6.1
(r= -0.46;	Lime	0-15	26.4	46.1	5.6	25.2	96.7	7.6	49.7	50.3	7.7
p≥0.05)		15-30	17.3	39.5	5.6	19.6	84.6	7.6	33.7	48.7	7.8
	TSP	0-15	26.4	46.1	5.6	29.3	96.4	5.3	37.8	79.9	5.9
		15-30	17.3	39.5	5.6	25.1	90.5	5.6	24.4	73.8	6.0
	DAP	0-15	26.4	46.1	5.6	54.0	109.4	4.8	94.9	81.2	5.0
		15-30	17.3	39.5	5.6	48.9	111.2	4.0	79.6	76.0	4.9
	AS	0-15	26.4	46.1	5.6	70.5	91.3	4.0	79.6	81.3	4.8
		15-30	17.3	39.5	5.6	47.4	76.4	4.6	73.9	62.7	4.9
Katumani luvisols	Control	0-15	7.6	7.5	6.6	63.4	7.8	6.0	61.9	15.8	6.6
		15-30	5.8	7.7	7.0	41.4	7.7	6.6	48.1	17.6	6.9
	TSP	0-15	7.6	7.5	6.6	71.2	8.3	6.4	90.8	18.7	6.8
(r= -0.66;		15-30	5.8	7.7	7.0	51.4	8.6	6.1	62.3	8.7	6.6
p≥0.05)	DAP	0-15	7.6	7.5	6.6	228.9	167.6	5.5	233.1	207.9	5.7
		15-30	5.8	7.7	7.0	193.2	165.8	4.3	199.1	185.0	5.0
	AS	0-15	7.6	7.5	6.6	219.6	162.9	5.4	222.5	177.2	5.9
		15-30	5.8	7.7	7.0	173.6	175.0	5.0	162.8	167.7	5.5

Legend: DAP: Diammonium Phosphate TSP: Triple superphosphate AS: Ammonium Sulphate Lime: Calcium carbonate NH_4-N: Ammonium nitrogen NO_3-N: Nitrate nitrogen R: Correlation between pH and NO_3-N

Nitrification increased throughout incubation period in the luvisols (Table 5) even when the pH dropped after addition of N and P salts. The drop in pH occurred after 60 days of incubation though nitrification proceeded and was highest when the N salts especially DAP were added and least in the control. Since Katumani luvisols are low in organic matter and total N, hence addition of N salts increased nitrifiable N in the soil compared to TSP and control treatments.

There was higher production of nitrates with DAP was added than with AS application in the three soil types. This difference is attributed to presence of P in DAP that interacted with N to boost microbial proliferation and activity (Munevar and Wallum, 1977). In all three soil types, nitrification decreased with depth while pH increased with depth. The variations in pH in the three soils could be due to OM content in each soil. Gituamba andosols with highest OM content had a slight pH change due to higher buffering capacity compared to the others. Kitale ferralsols and Katumani luvisols had drastic pH changes due to OM content which exhibits low buffering capacity.

CONCLUSIONS

Liming of soil raised the pH and had a marked effect on N-mineralization in Gituamba andosols which are highly acidic creating favourable conditions for microbial activity. In Kitale ferralsols, liming did not produce significant N-mineralization and this could be attributed to denitrification and volatilization of ammonia as pH increased above 7. Addition of N-salts increased production of mineral N, partly coming from added inorganic N sources and partly from soil nitrogen pool. Net N mineralization above the control was only observed in Katumani luvisols and Gituamba andosols. This suggested

priming effect where DAP, AS and TSP were added. But in Kitale ferralsols, N-mineralization was depressed by addition of N salts though addition of TSP showed some stimulating effect in this soil. In Gituamba andosols, addition of inorganic N salts produced considerable amounts of nitrates from added salts and from the soil N pool in both Gituamba and Kitale soils. However, in Katumani luvisols, production of nitrates was very high with addition of inorganic N salts. Nitrate production was positively correlated with soil pH in Gituamba andosols only. Nitrification in acid soils (Gituamba and Kitale) could be attributed to presence of acid adopted strains which are active at low pH levels. Kitale ferralsols had least amount of nitrates produced and this could be due to the nature of this soil being under grass cover and tends to retain more NH_4-N than NO_3^+.

RECOMMENDATIONS

- Better to lime Gituamba andosols than to add inorganic N salts to help exploit the accumulated organic N which when released becomes available to the crops.
- Not necessary to lime Kitale ferralsols as it does not increase N significantly
- Future studies necessary to determine threshold levels of liming various acid soils for maximum N mineralization. At the same time, liming of such soils should be done at the field and then studies on microbial N turnover to be carried on in-situ.

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